



# Motivation

Germany leads record wind power growth in Europe

Has EON really just ditched fossil fuels to go renewable?

España se ha gastado más de 50.000 millones en subvencionar las renovables



Axpo tief in den roten Zahlen

600 Millionen Subventionen für die Wasserkraft

## Schweizer AKW produzieren nicht mehr rentabel

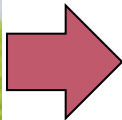
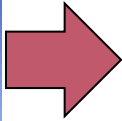
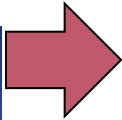
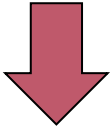
Die Kraftwerke laufen auf Vollast weiter, aber Verluste drohen

How to reform EU power markets: is a capacity market necessary?

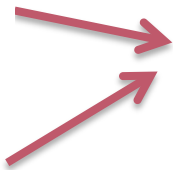
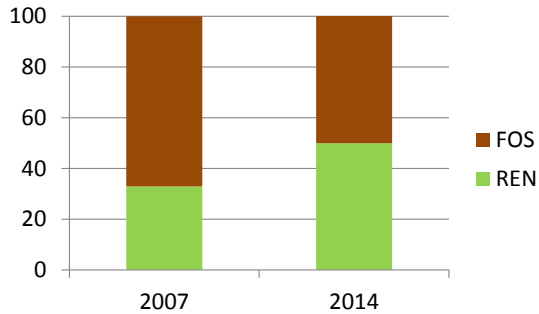
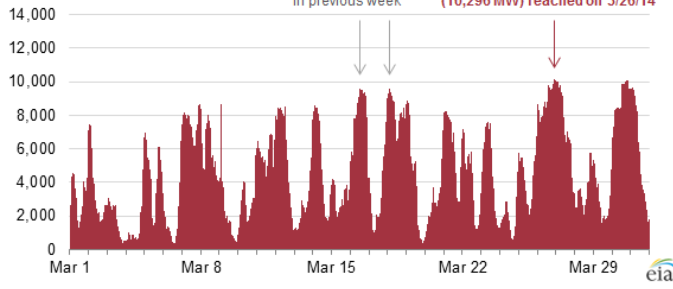


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Texas (ERCOT) hourly wind generation (March 2014)  
megawatts (MW)



Coal and gas prices

Market liberalization

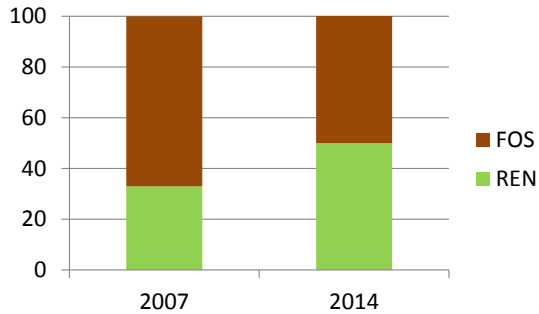
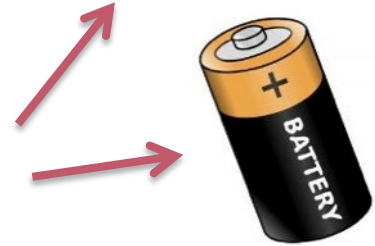
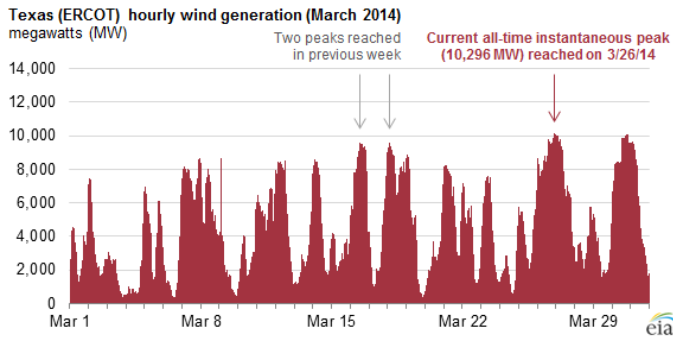
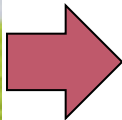
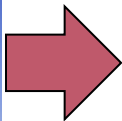
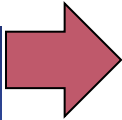
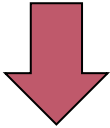
Carbon price / emission trading



WE NEED AN  
ELECTRIC POWER  
SUPPLY MASTERPLAN

**GOSH!!**

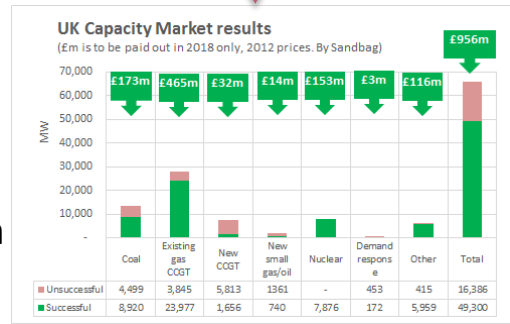




Coal and gas prices

Market liberalization

Carbon price / emission trading

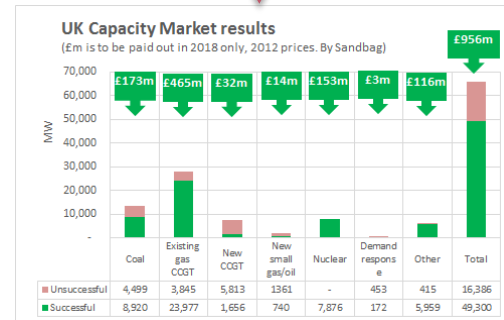
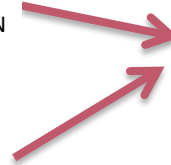
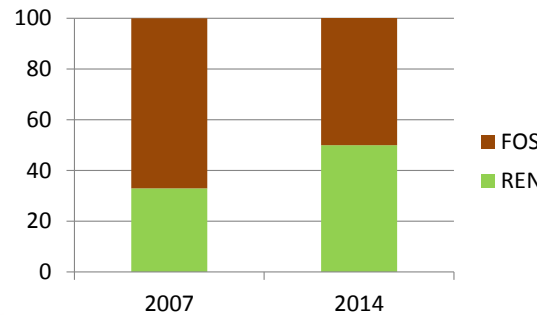
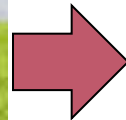
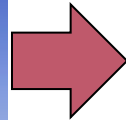


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# Research Question

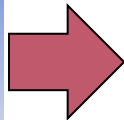
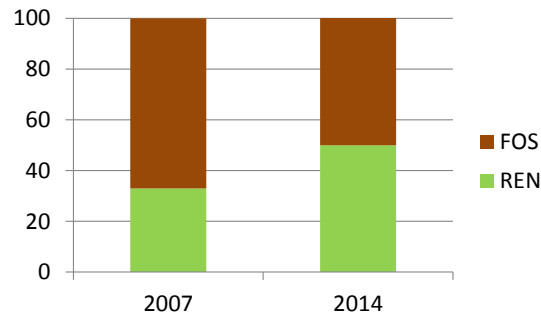
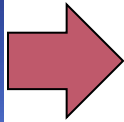
1. Quantify the impact of wind energy on the Spanish electricity markets
2. Implications for investments and future policy design





# Research Question

## 1. Quantify the impact of wind energy on the Spanish electricity markets

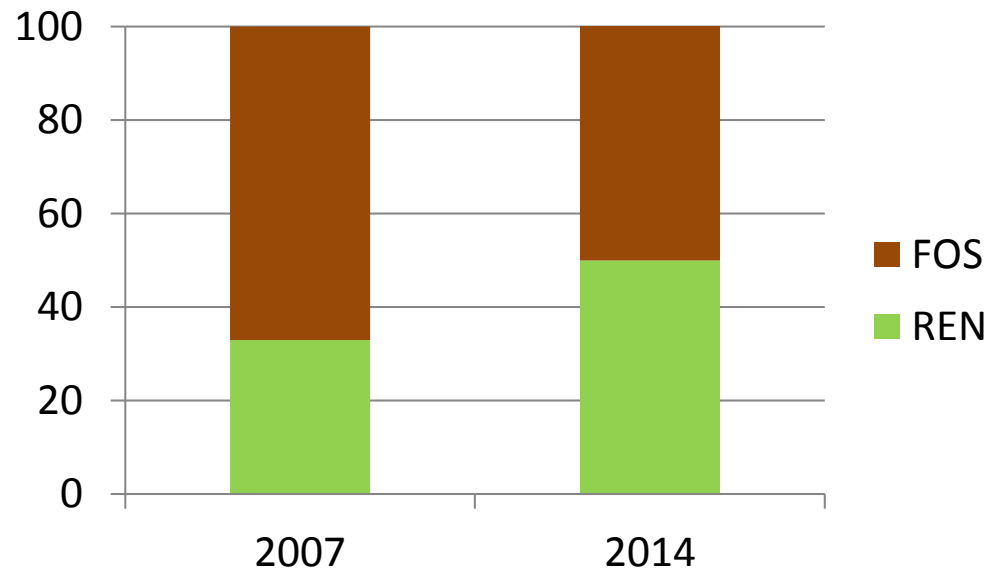


What is the **influence of wind generation on production levels** of coal, gas and nuclear energy?

What is the **influence of wind energy on the electricity spot prices?**

How large are the **revenue losses** of coal, gas and nuclear generation due to wind energy? And how is this effect decomposed into a price and a quantity effect?

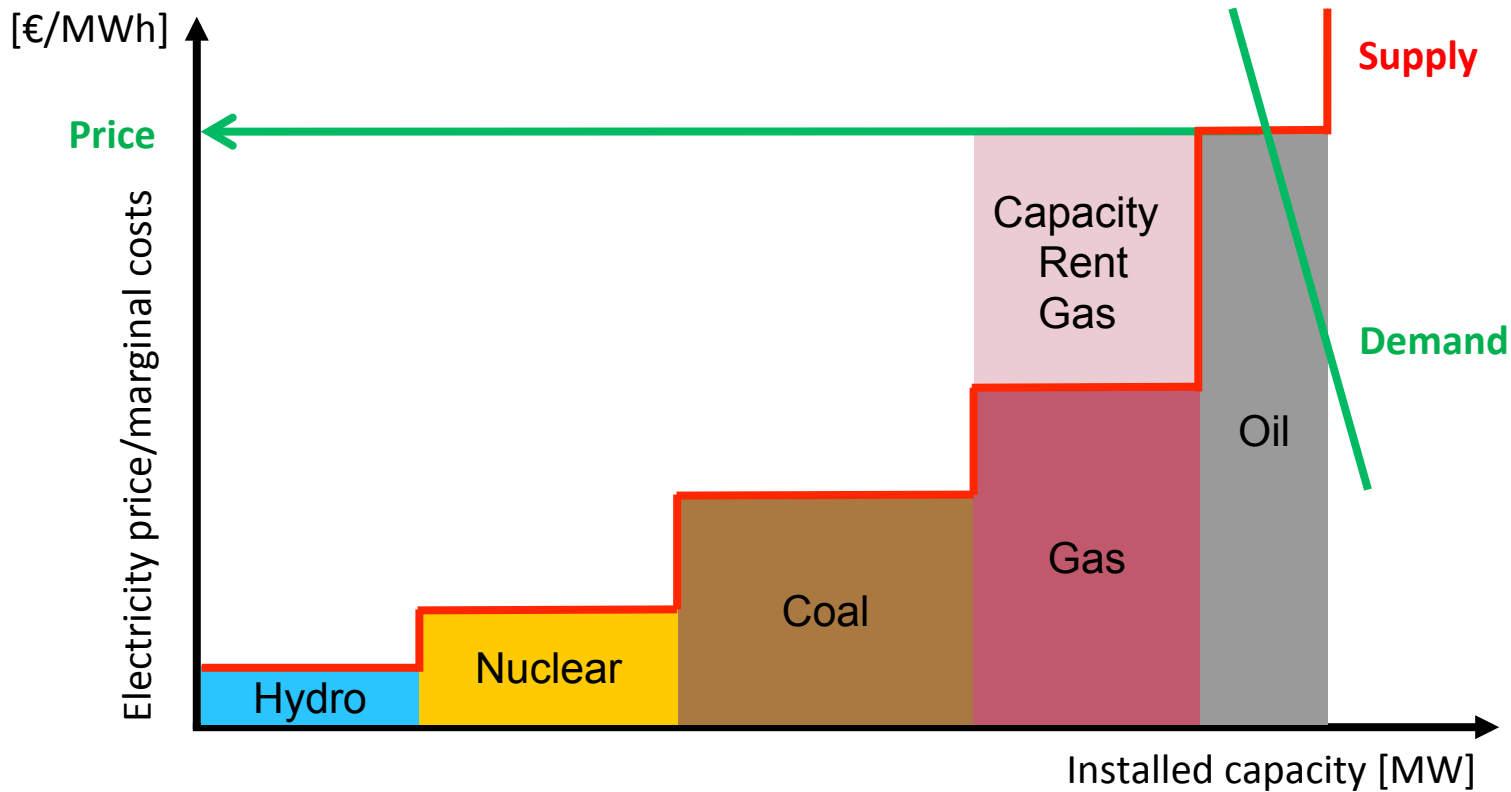
# Electricity Price and Generation Quantity



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# Terminology

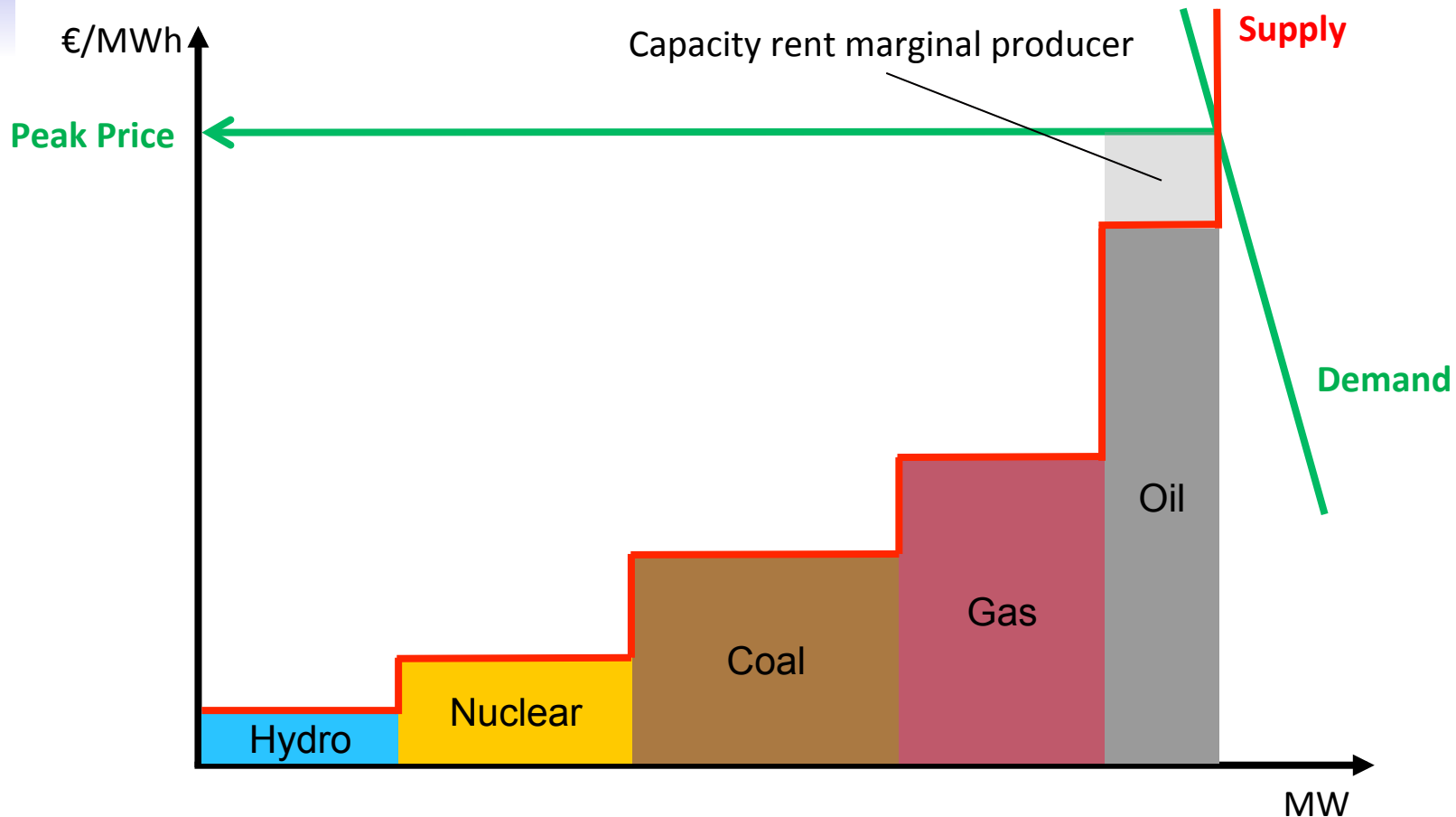


- Merit order curve, marginal and sub-marginal generators

- $Revenue_i = \sum_{h \in H} X_{hi} (P_h)$

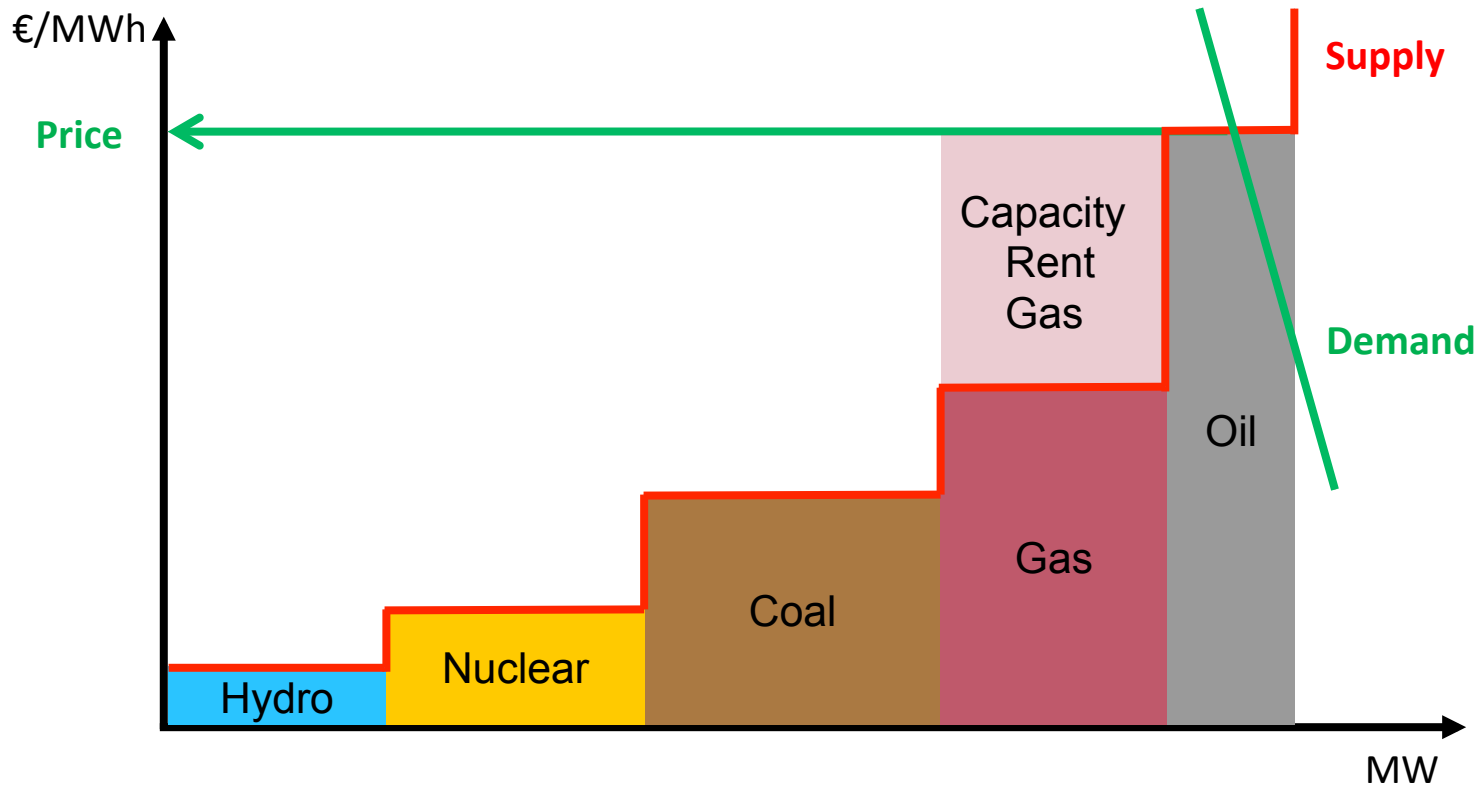
- $Capacity\ Rent_i = \sum_{h \in H} X_{hi} (P_h - mc_{hi})$

# Peak load pricing: Capacity rents for peak producers



- In peak hours marginal generators can earn capacity rents

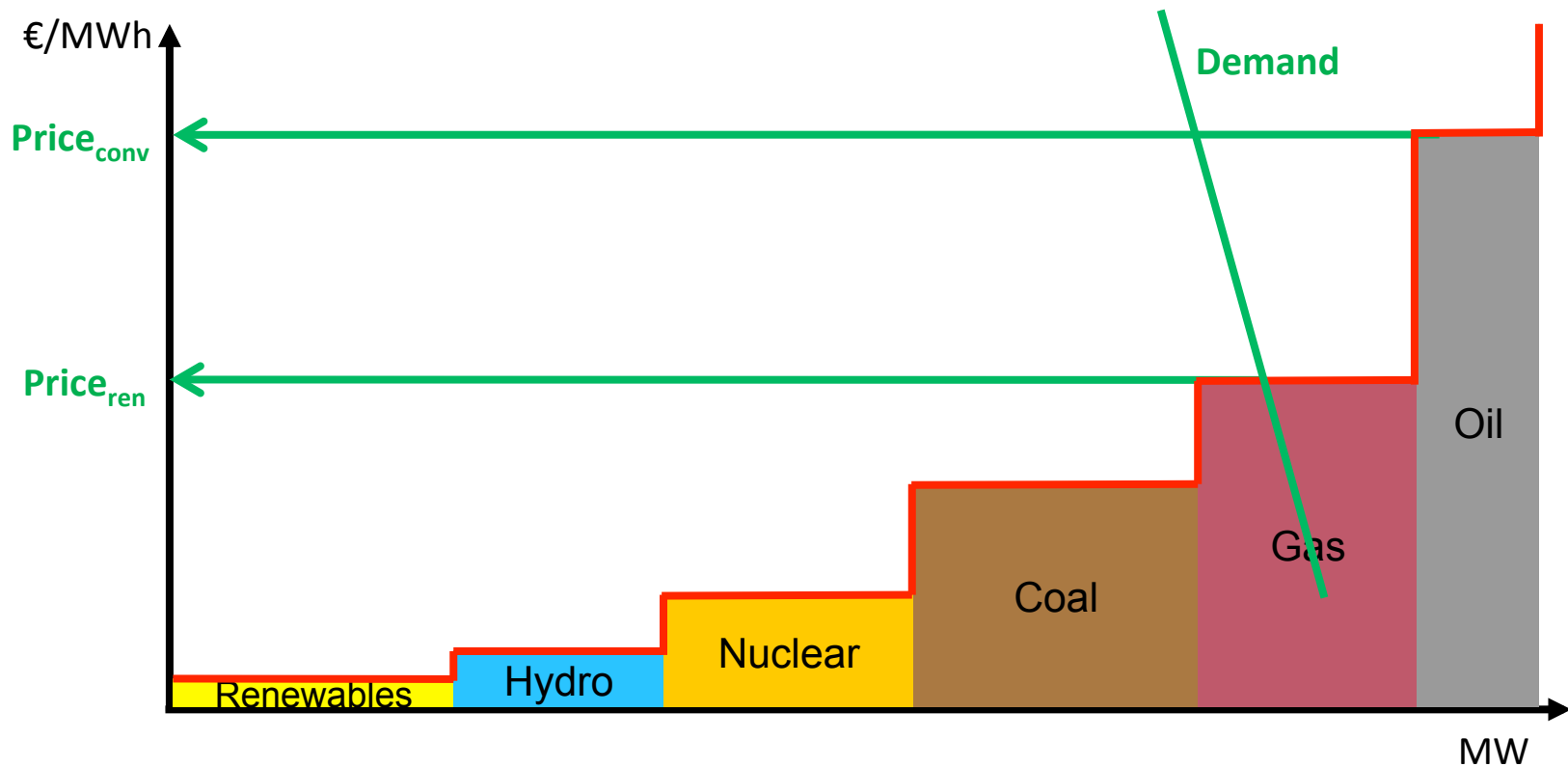
# Influence of Renewables



- What happens if renewable energies are added to the system?

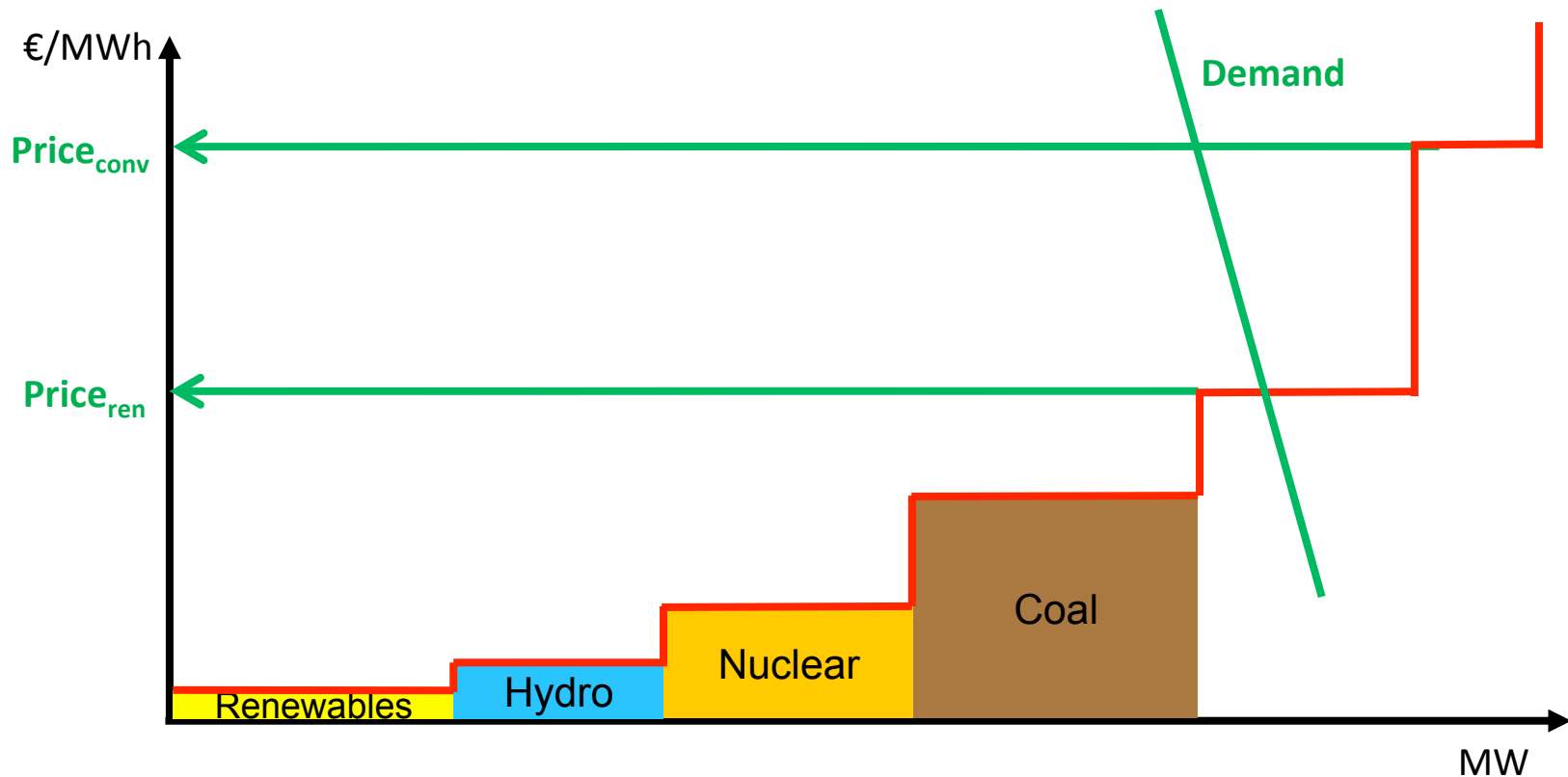


# More renewables lead to lower prices and less fossil generation



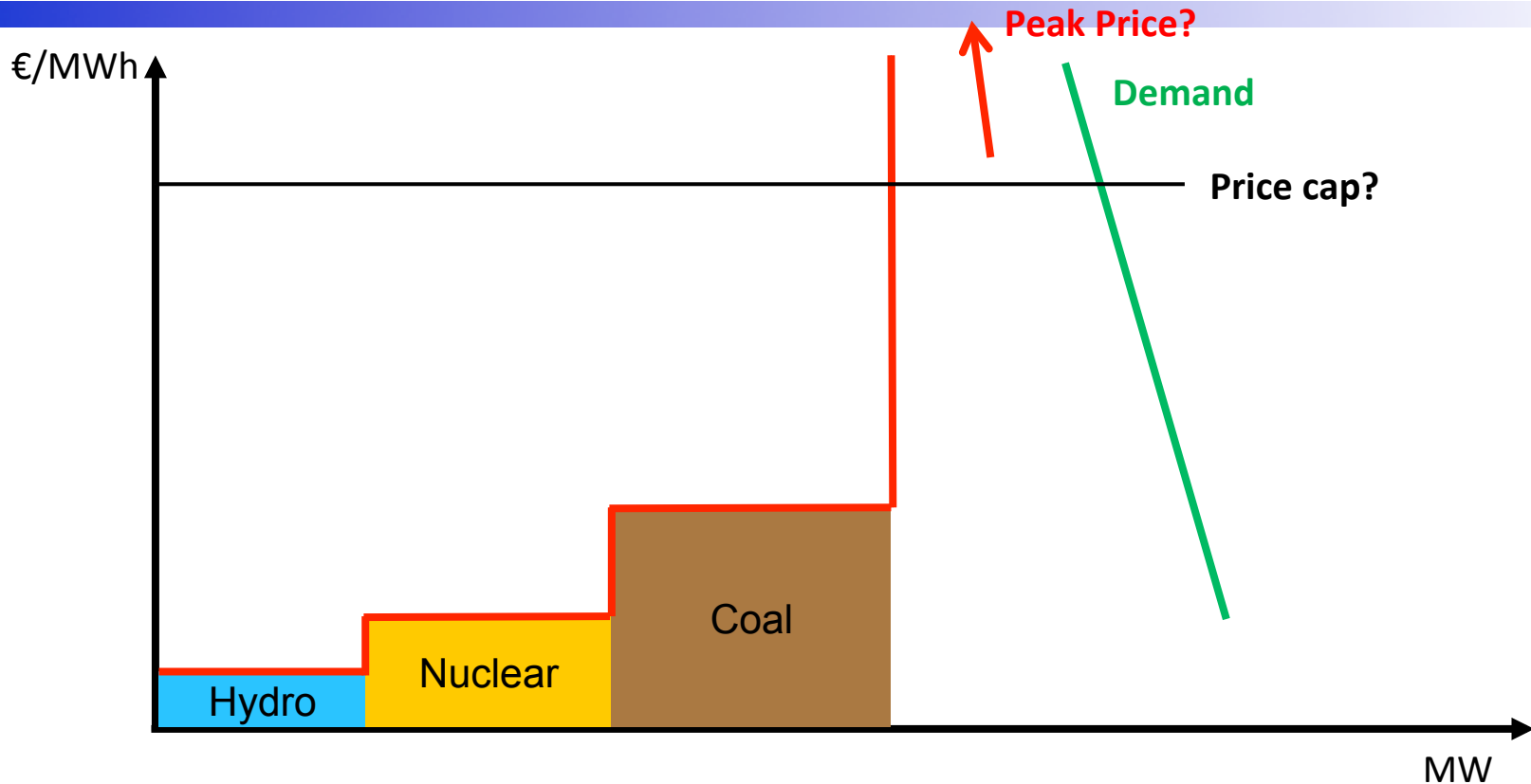
- Prices decrease because of changing marginal generators
- Technologies with high marginal costs have lower production levels
- Revenues decrease

# Remove excess capacity



- Replace fossil fuels by renewables
- Isn't this what we wanted?
- Yes, but... What happens if there is neither sun nor wind?

# Peak prices, price caps and capacity markets



- Very high peak prices in times without renewables
- Politically difficult: market power issues, risks for consumers and investors, etc.
- Price caps and capacity payments as a solution?
- Liberalization versus regulation

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# Literature

## Existing literature

- Focus on price effect (merit order effect)

## Research gap

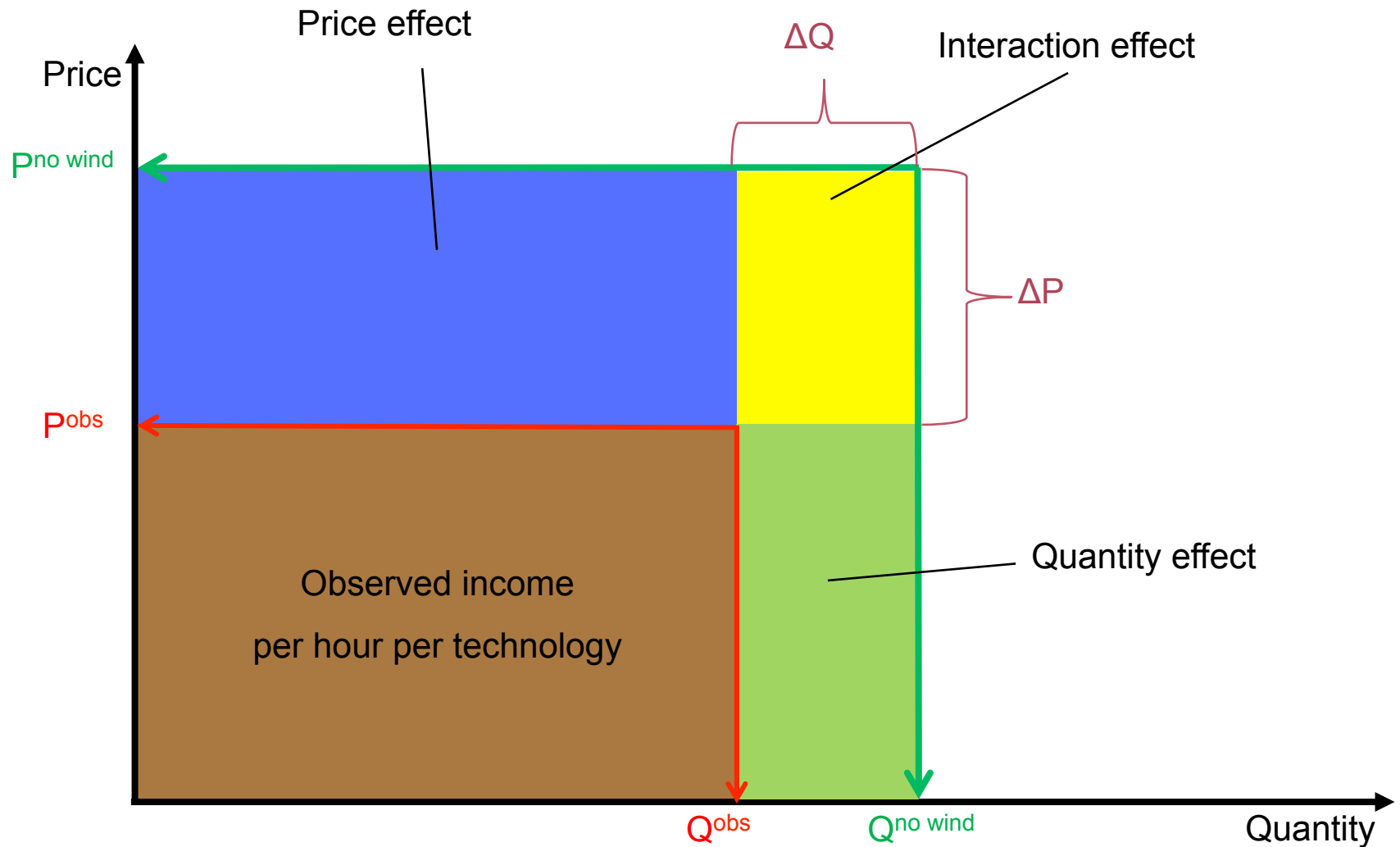
- Impact on revenue not yet quantified
- Decomposition into price and quantity effect

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# Decomposition of effect on revenue



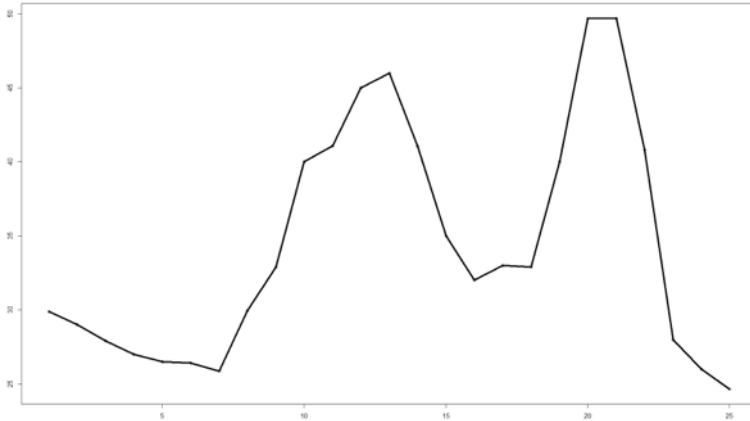
# Two Methods

We use two different methods to estimate  $\Delta P$  and  $\Delta Q$

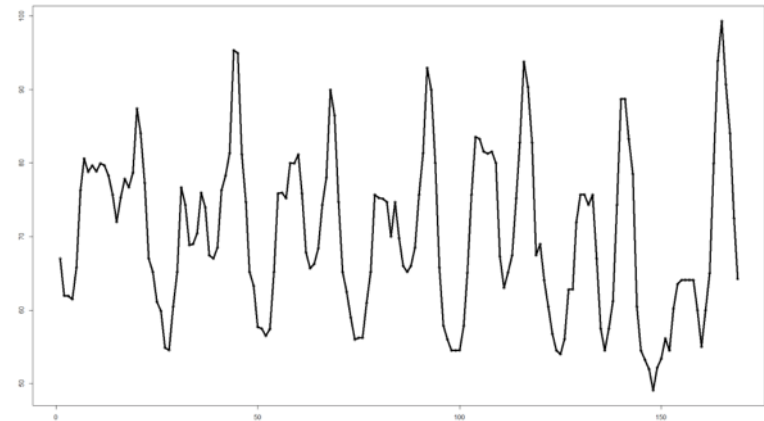
- Empirical analysis: Linear Regression Model
- Simulation: Electricity Dispatch Model

# Electricity prices depend on...

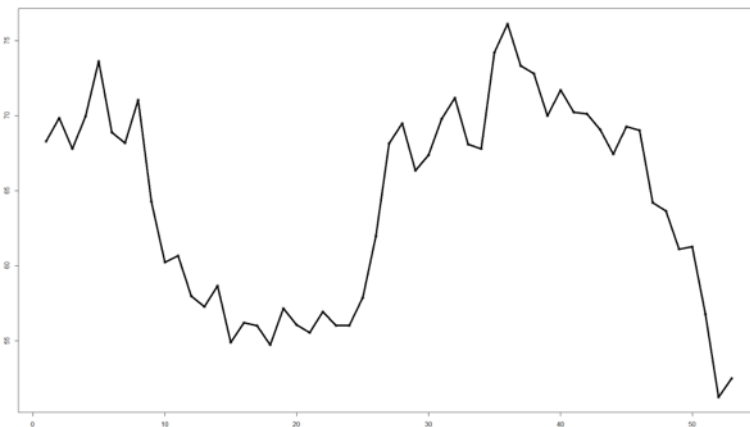
Daily cycle



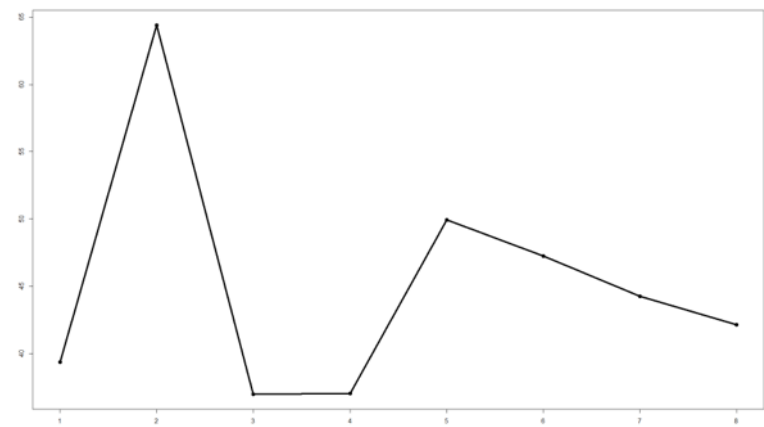
Weekly cycle



Yearly cycle



Longterm trends

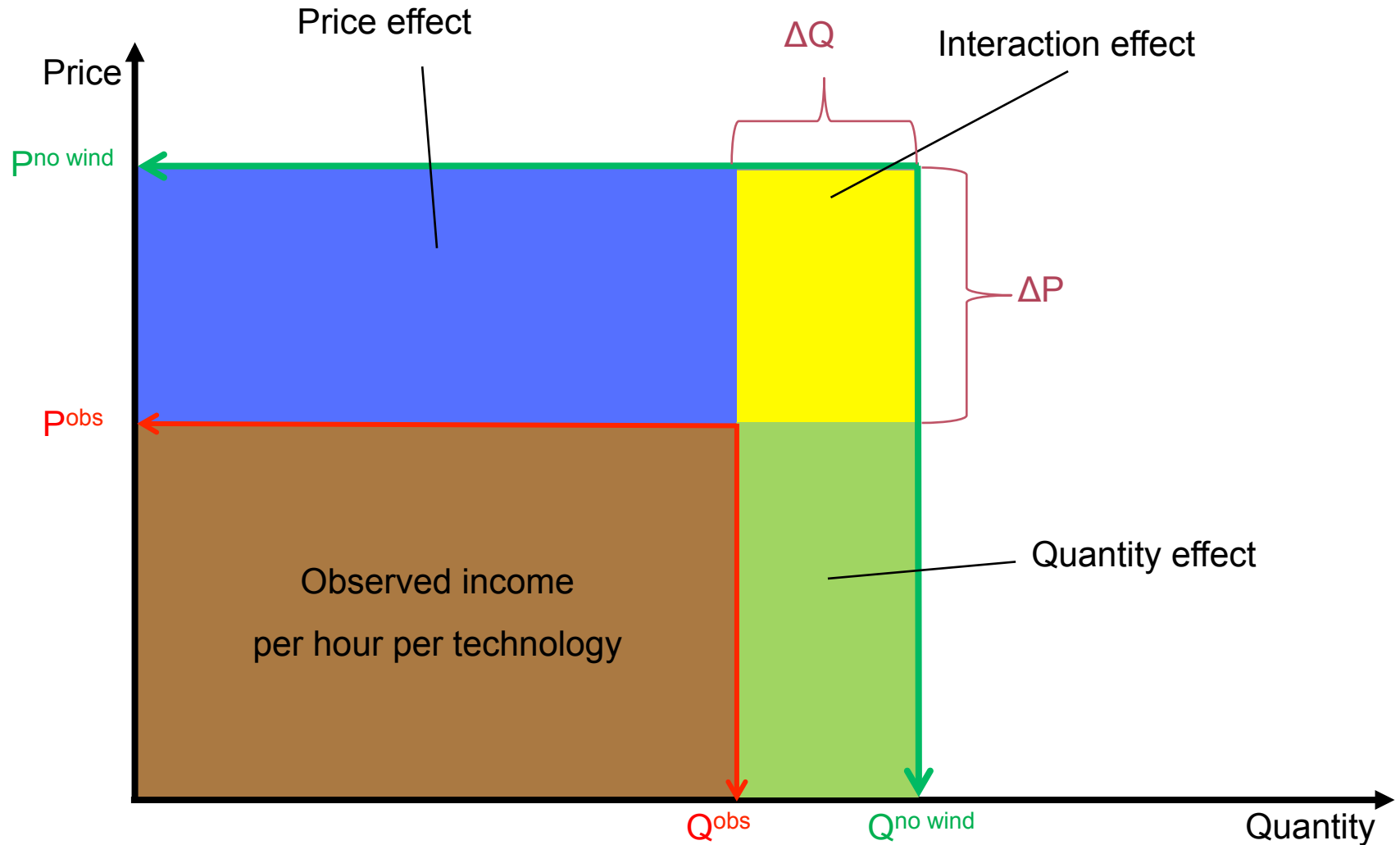


# Regression Model

$$P = \beta_0 + \beta_1 \text{wind} + \beta_2 \text{other ren} + \beta_3 \text{demand} + \beta_4 \text{peak hour} + \beta_d \text{week day} + \beta_m \text{month} + \beta_y \text{Year}$$

$$Q_{GAS} = \gamma_0 + \gamma_1 \text{wind} + \gamma_2 \text{other ren} + \gamma_3 \text{netdemand} + \gamma_4 \text{peak hour} + \gamma_d \text{week day} + \gamma_m \text{month} + \gamma_y \text{Year}$$

# Decomposition of effect on revenue



# Electricity dispatch model

$$\min COST := \sum_{it} C(X_{it}) + C^+(X_{it}^+) + C^-(X_{it}^-)$$

$$\sum_{it} X_{it} = d_t$$

**Market clearing of supply and demand**

$$\alpha_{it} cap_{it} \geq X_{it}$$

**Capacity constraint**



# Scenarios

Benchmark scenario  
(historical data)

No wind scenario

Total demand

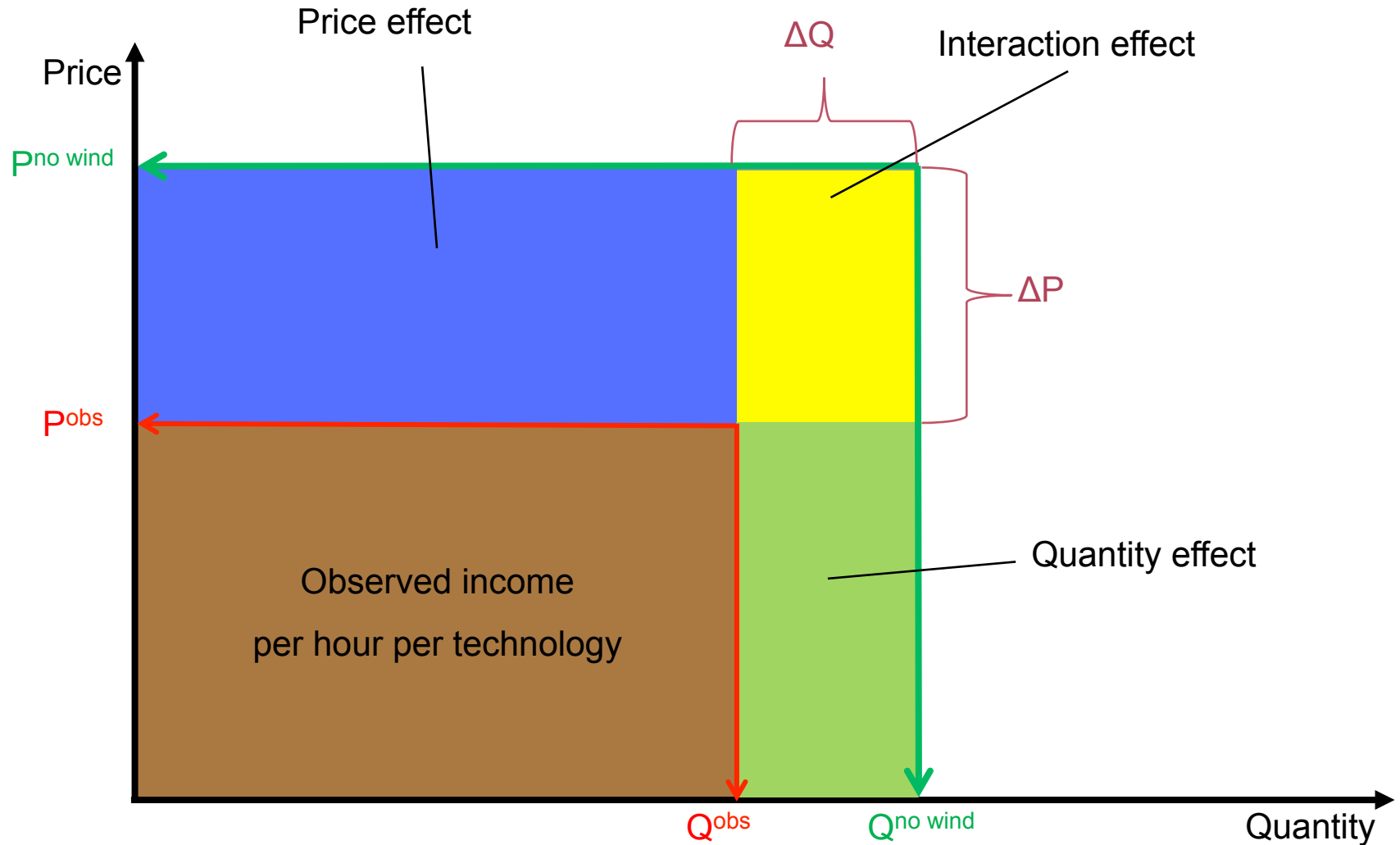


Fossil generation



Fossil generation

# Decomposition of effect on revenue



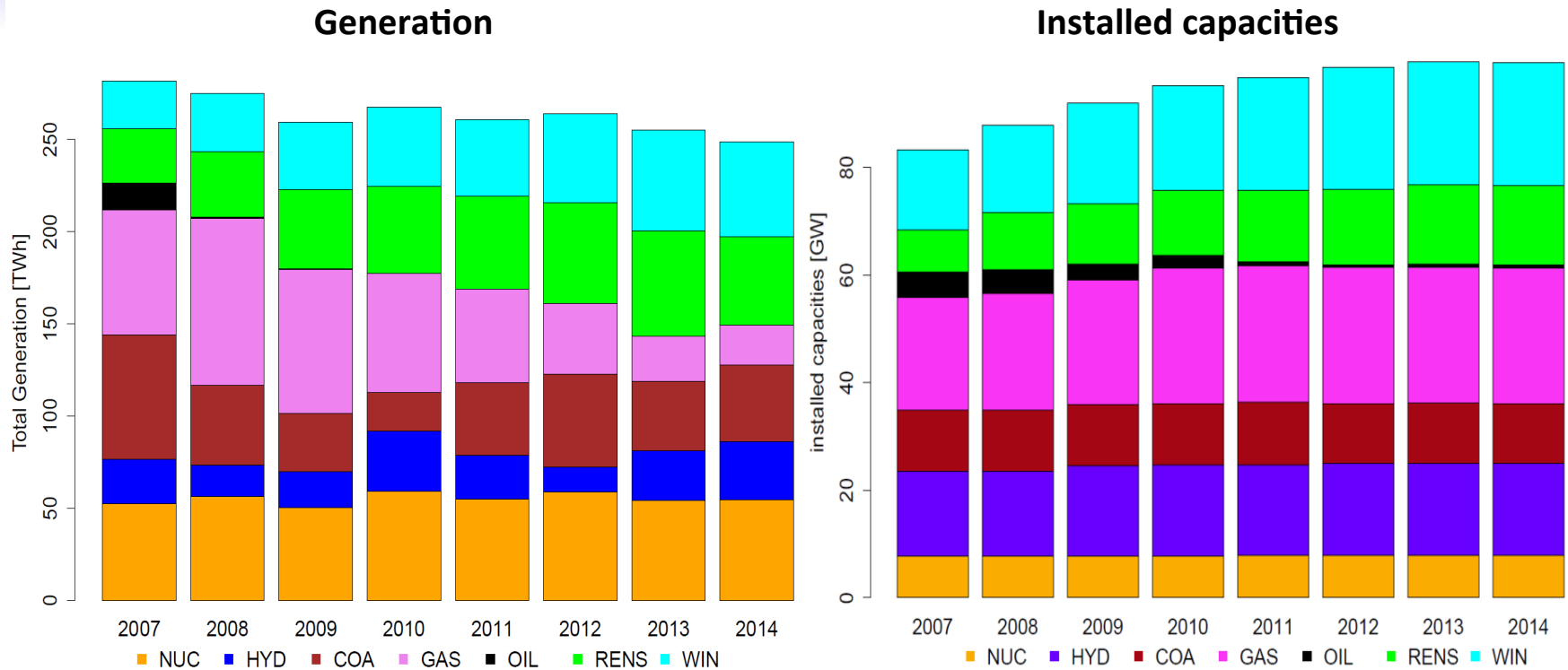
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# Data: The Spanish Electricity System 2007-2014

- Hourly generation data on technology level (Spanish TSO)
- Hourly wholesale market price data (Pen-insular market place)
- Yearly installed capacities (Spanish TSO)
- Availabilities from literature

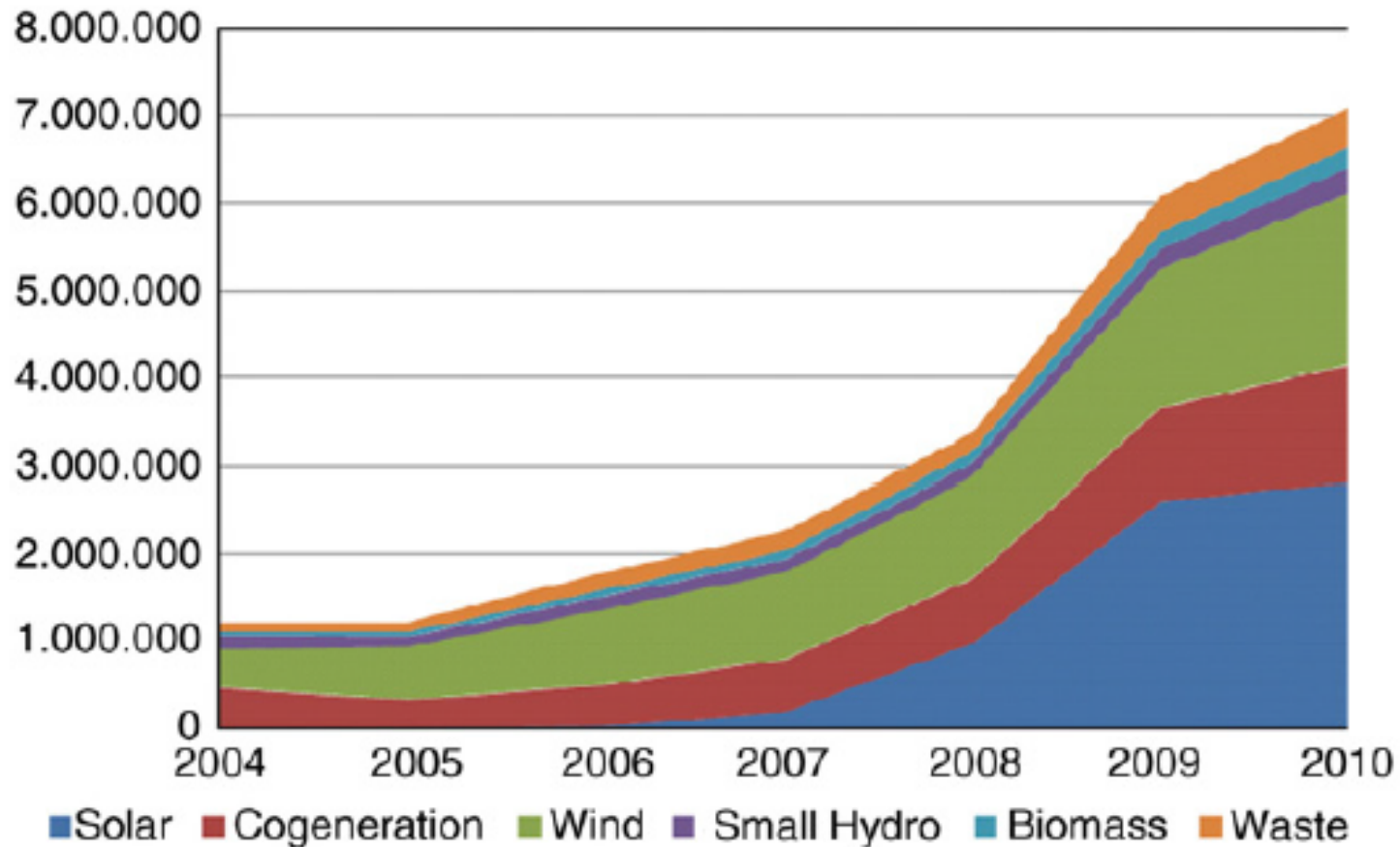
# Generation and installed capacities (Spain 2007-2014)



- Total generation slightly decreased
- Gas generation decreased
- Renewable generation increased

- Total installed capacity increased
- Conventional capacity constant
- Renewable capacity increased

# Support for renewables and cogeneration [€]



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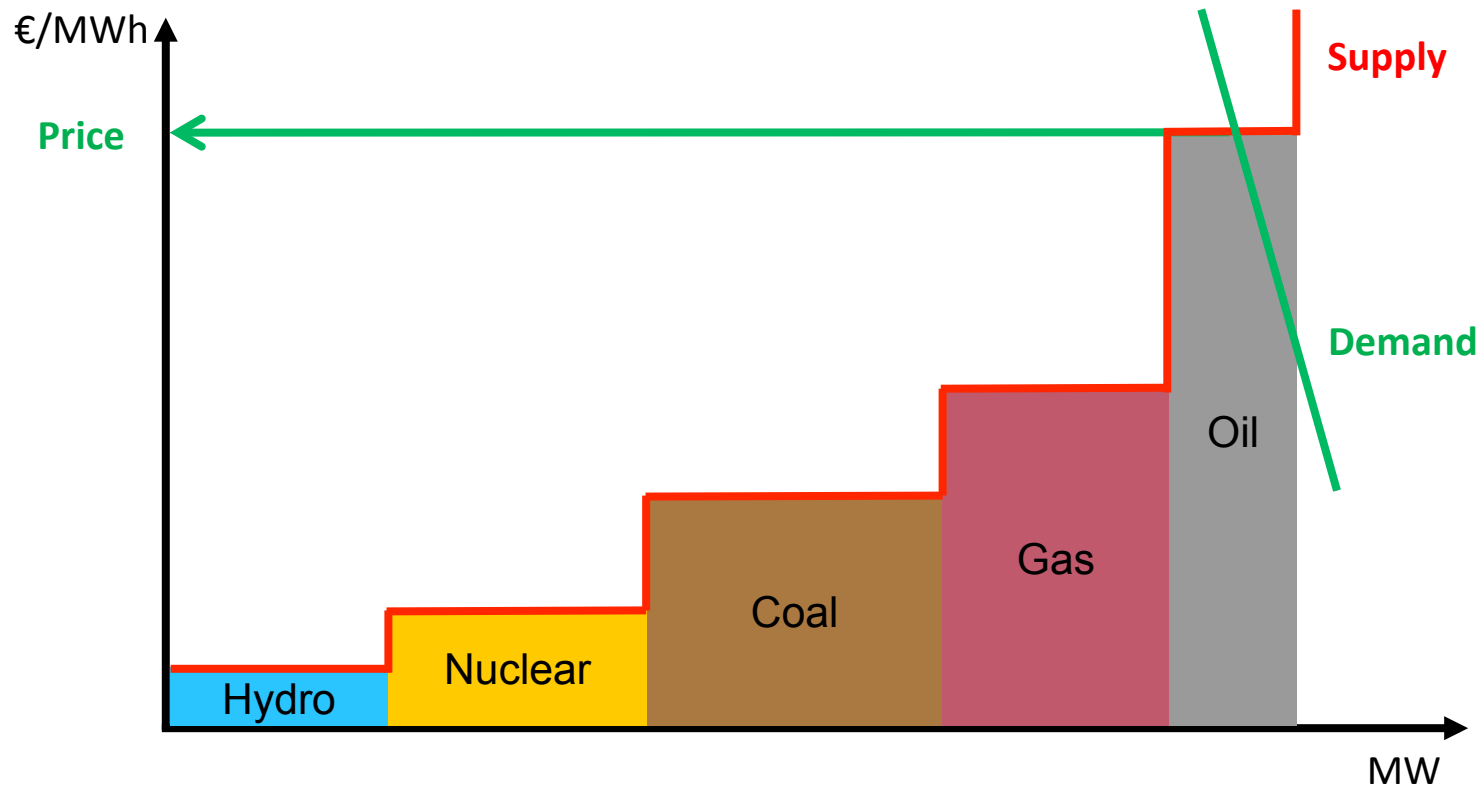
# Influence of wind on prices and generation

	Regression	Simulation
Price [€/MWh per GWh <sub>wind</sub> ]	-2.4	-2.0
Gas generation [GWh per GWh <sub>wind</sub> ]	-0.45	-0.59
Coal generation [GWh per GWh <sub>wind</sub> ]	-0.34	-0.41
Nuclear generation [GWh per GWh <sub>wind</sub> ]	-0.03	-

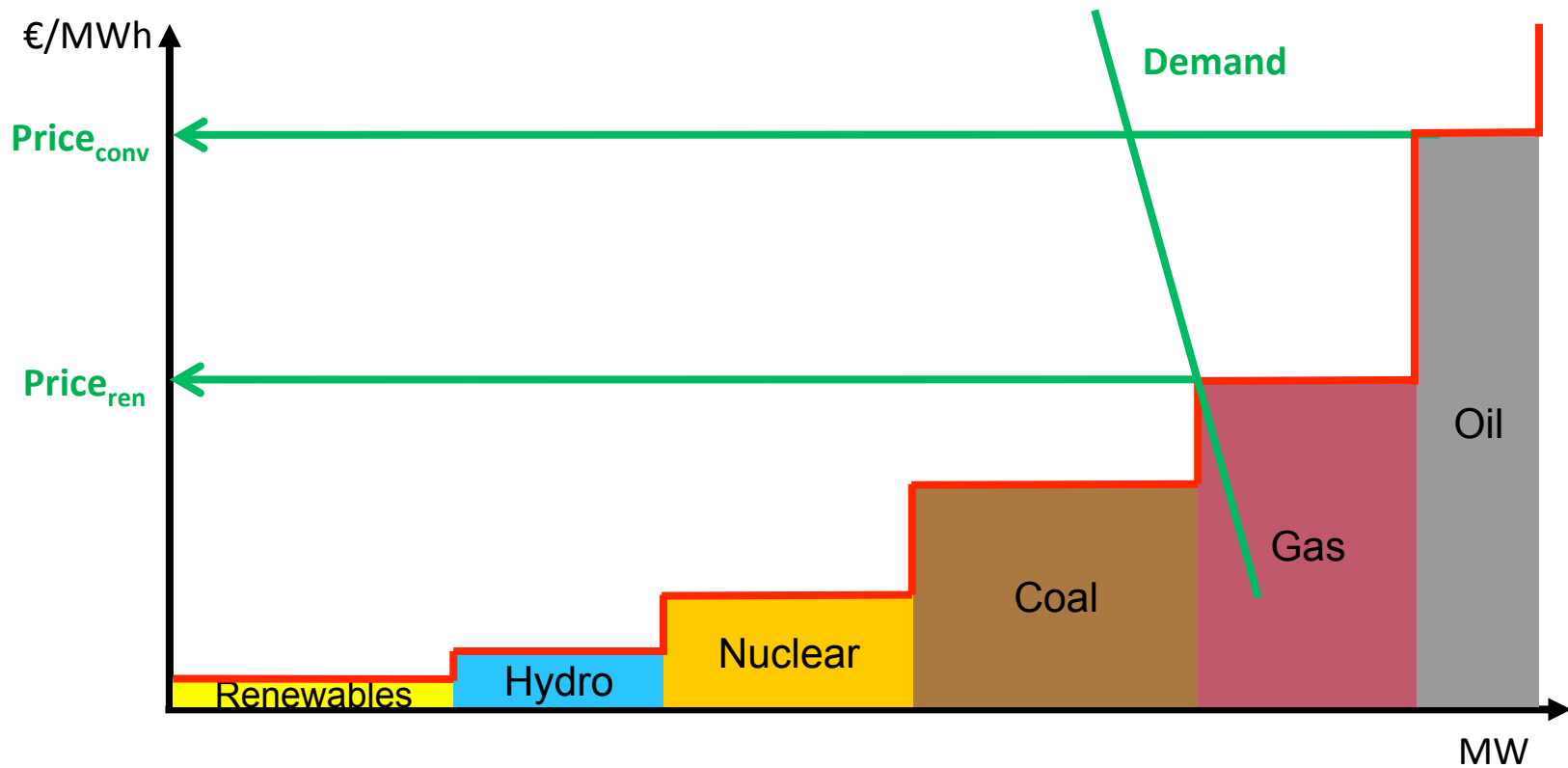
- Results are comparable to literature.
- Results correspond to theory of merit order effect.



# Changes in merit order curve



# Changes in merit order curve

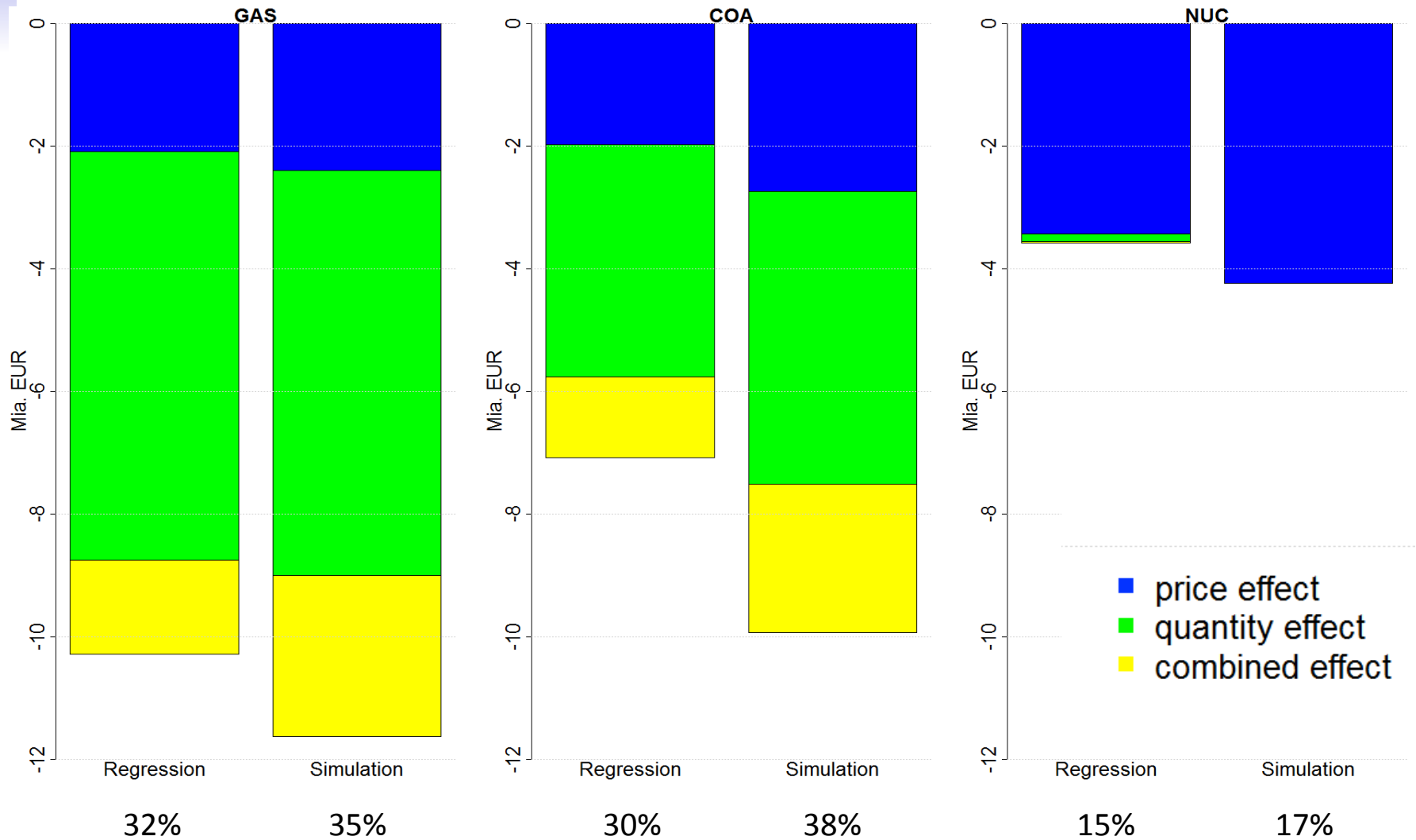


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- Differences between regression and simulation:  
No Pump Storage simulation because of lack of data  
→ total wind energy balanced by gas and coal

# Influence of wind on absolute revenue



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# First conclusions

- Revenue of conventional technologies decreases because of wind
  - Coal and gas: quantity effect dominates, but price effect not neglectable
  - Nuclear: price effect dominates, almost no quantity effect
- Decreasing incentives to invest in new or maintain existing capacity

# Open questions & next steps

- How much dispatchable capacity do we need?
- Will this capacity be provided by the free market or do we need additional instruments, e.g., capacity payments?

→ Next steps of my PhD...😊